Intraoperative Ultrasound of the Liver

An Important Adjunctive Tool for Decision Making in the Operating Room

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Forty-nine patients operated on for liver or other pathologic processes were examined intraoperatively with special ultrasound transducers during surgical exploration of the abdomen. Subjects were evaluated because of known or suspected disease of the liver. All patients were examined using sterile technique. Prospective diagnosis and retrospective analysis of data were used. In 55% of subjects, no new information was obtained. In 19%, new information was gathered that changed the surgical approach. In 14% of patients, new information was obtained but it was such that no change in the therapeutic approach was needed. In 12% of patients, although no new information was gathered by the use of intraoperative ultrasound, a change in the surgical approach and management of the patient was still possible because of intraoperative ultrasound. These studies show that the routine use of ultrasound during intraoperative procedures, particularly when involving hepatic structures, is a clinically useful technique. In many instances, it will change the course of management.

THE USE OF INTRAOPERATIVE ULTRASOUND was established in the 1960s but the technique was not used extensively because the available equipment was difficult to use. Thus, the technique did not attract much attention for the first two decades after its introduction. In the early 1980s, with refinement in machinery, intraoperative ultrasound became a useful diagnostic technique particularly in neurosurgical procedures.[1-4] Intraoperative guidance for renal calculi removal, a previously important use of intraoperative ultrasound, is not as frequently used today because of the percutaneous treatment of kidney stones. More recently, intraoperative ultrasound has been used as a complementary procedure for many routine, as well as complicated, general surgical procedures. Delineation of hepatic, biliary, and pancreatic tissue now can be clearly demonstrated and the efficacy of the technique is becoming more widespread.[5-10]

Although the use of intraoperative ultrasound has been established as an effective tool to delineate liver pathology, its ability to alter the therapeutic (surgical) approach to the patient's problem has not been as clearly delineated.[11-15] We performed a study using prospective diagnosis and retrospective analysis of data to evaluate the benefits of intraoperative ultrasound of the liver in a group of patients with possible hepatic pathology.

Methods and Materials

Forty-nine patients were included in this study. Although not every patient having surgery was studied by intraoperative ultrasound, all patients that were examined by sonography are included in this analysis. Patients were selected because of the following: (1) known liver disease, *i.e.*, known or suspected space-occupying lesions or duct dilatation and (2) unproven liver pathology but with a high possibility of involvement, *i.e.*, patients with rectal or colonic carcinoma with possible metastatic lesions to the liver.

All patients had routine preoperative right upper quadrant imaging studies including conventional ultrasound, computed tomography, and/or angiography.

The patients were examined during operation with a 7.5-MHz linear array transducer (Fig. 1) attached to a specially produced intraoperative ultrasound machine, an Aloka 330 (Aloka, Tokyo, Japan). The ultrasound machine was manufactured with simplified controls for use in the operating suite. All controls were minimized and

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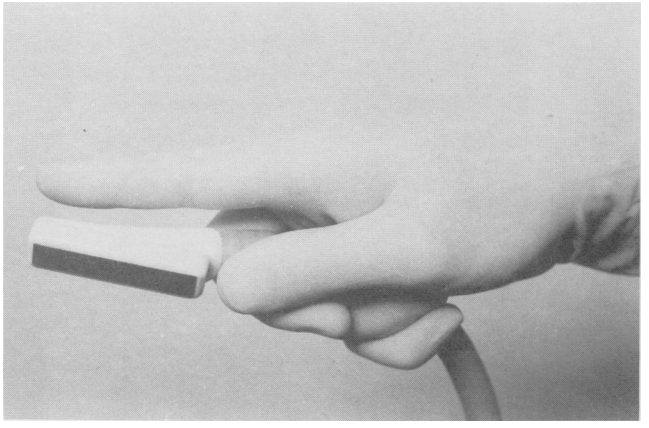


FIG. 1. Intraoperative transducer. The intraoperative transducer is smaller than the finger.

access was *via* the top of the machine covered with a disposable sterile sheath (Fig. 2). Theoretically the surgical team alone could activate and run the apparatus without a break in sterile technique. The intraoperative probe was small enough to fit between two fingers of the palpating hand. Although the transducer and the transducer cable could be gas sterilized, this would require 48 hours aeration; therefore, we used disposable, sterile sheaths to cover the transducer (Fig. 3). This allowed repeated use on sequential patients without the lengthy period required by gas sterilization. Acoustic gel was used to interface the transducer crystals to the sterile covering. Commercially available intraoperative latex sheathing was used in all cases. Sterile rubber bands secured the covering to the transducer cable. An arthroscope drape was used to cover the full length of the cable (10 feet). Permanent recording to the ultrasound images was made on a video cassette recorder that was incorporated into the ultrasound machine. The ultrasound image was 4 cm wide with a maximum 8-cm depth.

The entire liver was imaged in both longitudinal orientation (sagittal) and transaxial orientation. The liver was scanned starting from the lateral aspect of the right lobe. The transducer was placed inferior and lateral and moved toward the left to the round ligament with continuous ultrasound scanning. The lateral segment of the left lobe was similarly imaged. When needed, particularly in an enlarged organ, the transducer was placed on the underside of the liver and scanning was commenced with the transducer angled cephalad. Contact between transducer and the liver was by natural peritoneal fluid or sterile saline.

When unsuspected nonpalpable lesions were imaged, ultrasound-guided biopsies were performed as indicated. In these cases, the biopsy needle was positioned adjacent to the transducer and the needle placed into the area of abnormality under continuous ultrasound control.

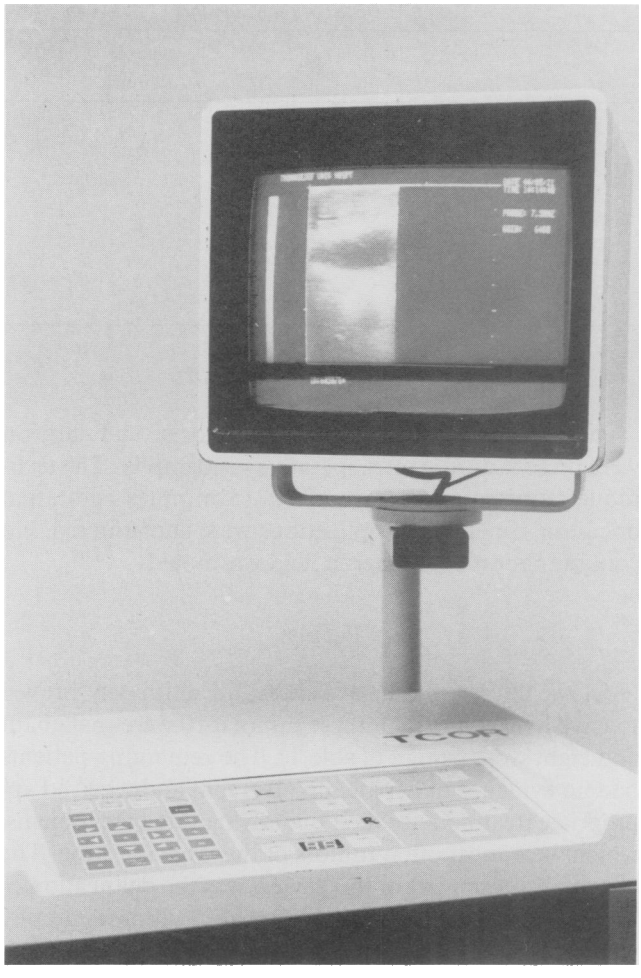


FIG. 2. Intraoperative ultrasound machine. Although conventional ultrasound equipment can be used, a specially produced unit was used for this study. This machine has single touch controls that can be easily covered by a sterile sheath.

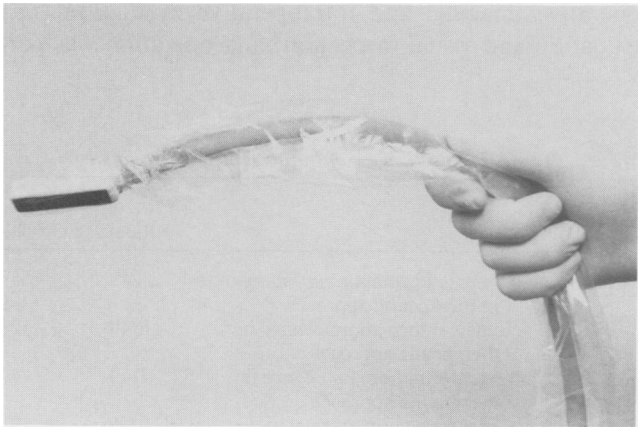


FIG. 3. Sterilized ultrasound transducer. A disposable sterile latex cover is used to ensure sterility over the transducer and the flexible cable.

TABLE 1. *Distribution of Tumors*

	No. of Tumors
Benign (N = 8)	
Hemangioma	2
Granuloma	2
Simple cyst	3
Adenoma	1
Malignant (N = 10)	
Primary	2
Metastatic	8

In this series, an experienced sonologist and surgeon were present during intraoperative sonography. The technique required an average of 10–15 minutes additional operating time. No complications were encountered. No contamination of the sterile field was noted.

Results

Of the 49 patients in this study, 18 ultimately proved to have liver tumors. Of these tumors, 10 were malignant and eight were benign (Table 1). The remaining patients had no evidence of hepatic involvement and received appropriate treatment for their underlying surgical problems, which were most often tumors of the large intestine. The essential component of this review was the delineation of the influence that operative hepatic ultrasonography would have on the extent and type of surgery performed. To analyze this, we divided all the patients into four groups (Table 2).

Group 1

This group comprised patients in whom no new information was obtained by operative ultrasound. The intraoperative ultrasound findings were consistent with preoperative imaging, and intraoperative evaluation (*i.e.*, palpation and visual inspection) and operation was performed as planned (Fig. 4). Twenty-seven of 49 patients (55%) were included in this group.

TABLE 2. *Effectiveness of Intraoperative Ultrasound*

Group		No. of Patients	%
1	No new information: *no change* in therapeutic approach	27/49	55
2	No new information: *change* in therapeutic approach	6/49	12
3	New information: *no change* in therapeutic approach	7/49	14
4	New information: *change* in therapeutic approach	9/49	19

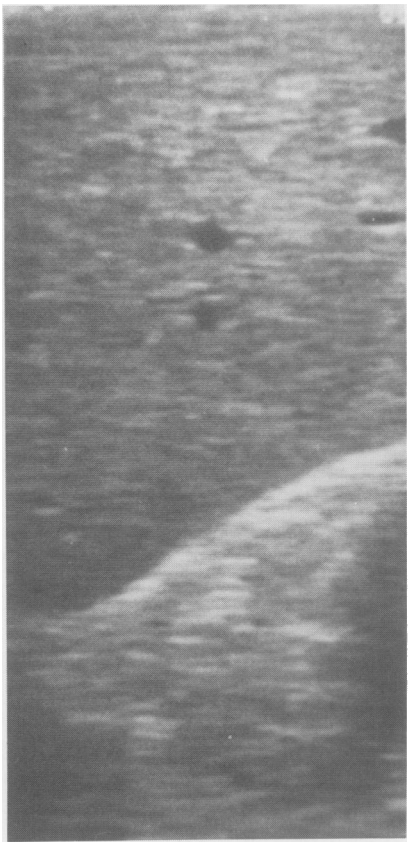


FIG. 4. Normal liver. Intraoperative ultrasound demonstrates normal echogenic liver texture without evidence of mass.

Group 2

This group comprised patients in whom the intraoperative ultrasound demonstrated no new information but the planned surgical treatment was altered because of the results of the sonogram. Included are those patients with a lesion known by preoperative studies but in whom the abnormality could not be seen nor felt at operation. Thus, ultrasound guidance for biopsy (Fig. 5) and/or excision was used, making the operation more precise and usually less extensive than it would have been without the ultrasound. This group included 6 of 49 (12%) patients.

Example. A 43-year-old woman on birth control pills for 12 years was studied because of chronic right upper quadrant pain. A preoperative arteriogram and computed axial tomography (CAT) scan were suggestive of hemangiomas of the right lobe, but the technetium-labeled autologous red cell scan was inconclusive. At surgery, the exact location could not be seen nor palpated. The ultrasound indicated its subcapsular location (Fig. 6) and allowed liver incision for enucleation of this vascular tumor.

Group 3

This group comprised patients in whom new information was obtained from the intraoperative ultrasound. However, the information produced no change in the planned approach. Seven of 49 (14%) patients were included in this category. The findings were mostly benign tumors, simple cysts, unsuspected gallbladder disease (Fig. 7), or granulomas (Fig. 8).

Example. A 72-year-old woman had curative resection of a Dukes C1 left colon lesion 18 months previously. Because of a rising CEA, a CAT scan was performed demonstrating a single right lobe lesion, which by arteriogram appeared highly suspicious for metastatic tumor. At operation, a second lesion was detected by intraoperative ultrasound on the left lobe, and this small lesion was found at biopsy to be a granuloma. A right hepatic lobectomy was then performed.

Group 4

This group comprised patients in whom new information was obtained during the intraoperative sonogram, which changed the surgical approach. This group included those patients with negative preoperative studies who by operative ultrasound were found to have hepatic metastases, usually from colon cancer. It also included patients with a preoperative suspected single lesion, where multiple lesions were identified (Fig. 9) and either resection had to be abandoned or multiple segmental resections or formal lobectomy performed. Additionally, this group included patients in whom preoperative studies suggested the presence of a liver lesion, but the intraoperative ultrasound demonstrated the liver to be normal and free of disease. There were nine of 49 (19%) patients included in this category.

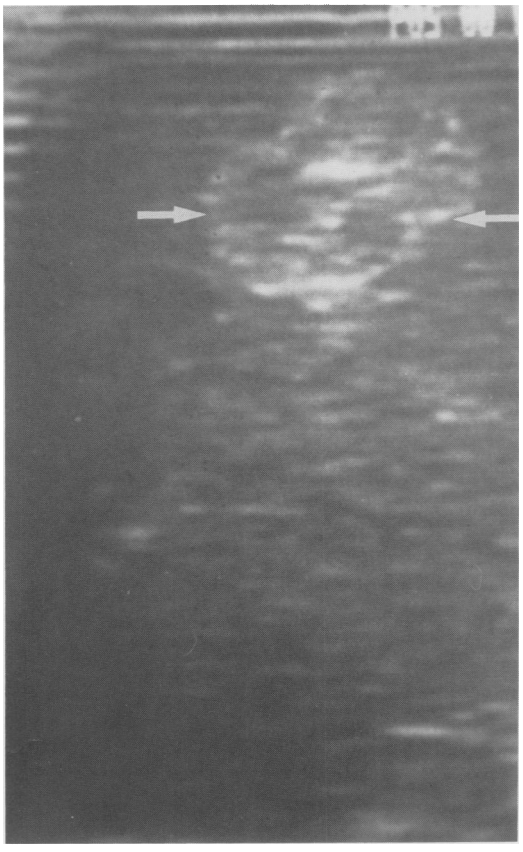
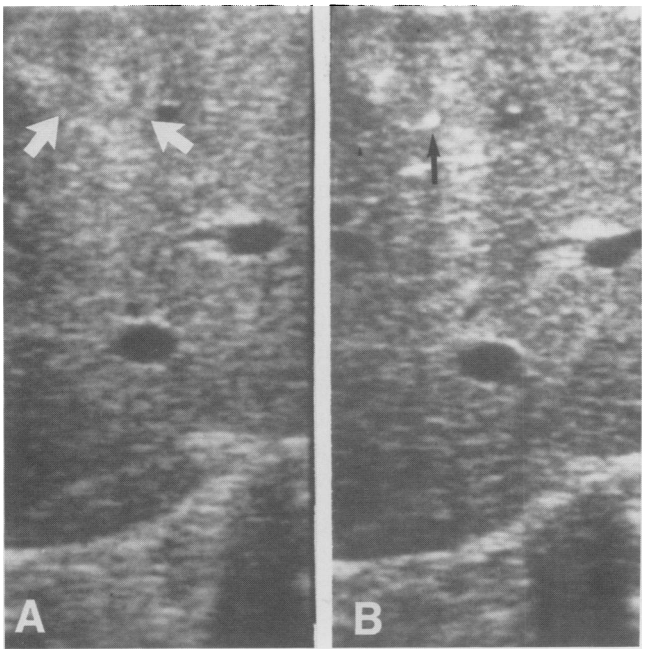


FIG. 6. Hemangioma. A well-defined, relatively echogenic mass (arrows) is identified. This is a typical appearance for an hepatic hemangioma.



FIGS. 5A and B. Nonpalpable hepatoma. An irregularly marginated, mixed echogenic lesion (arrows) is seen in the right lobe of the liver (*A*). Because this lesion was not palpable, a biopsy needle was placed within the liver under ultrasonic guidance. The tip of the biopsy needle (arrow in *B*) is seen.

In comparing the effectiveness of the various imaging techniques, we see that overall, operative ultrasonography is the most sensitive (Table 3).

The comparative sensitivity and specificity of the other imaging studies are presented in Table 4. For this analysis, a study was called false-positive if a lesion was suspected by a diagnostic technique and not corroborated at operation. A false-negative included those cases where a lesion was found at surgery but the given diagnostic technique did not detect its presence. These definitions are based on the simple presence or absence of tumor but not on the detection of the absolute number of lesions.

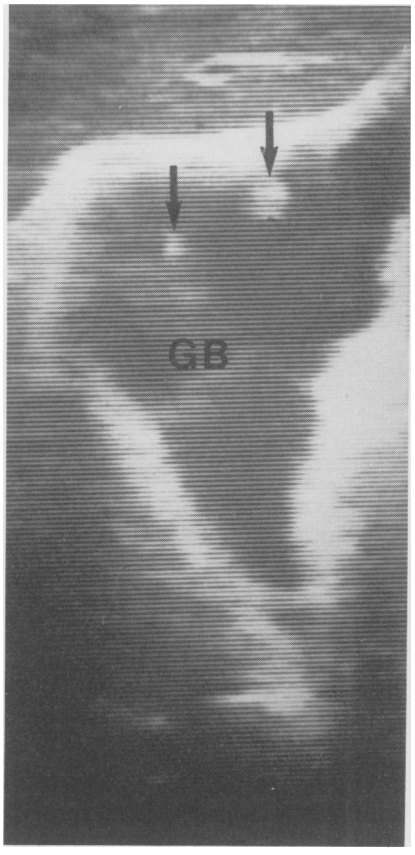


FIG. 7. Gallbladder polyps. Nonpalpable, unsuspected gallbladder polyps are noted within the gallbladder. These polyps (arrows) are echogenic but do not cause sonographic shadowing that would be identified with gallstones.

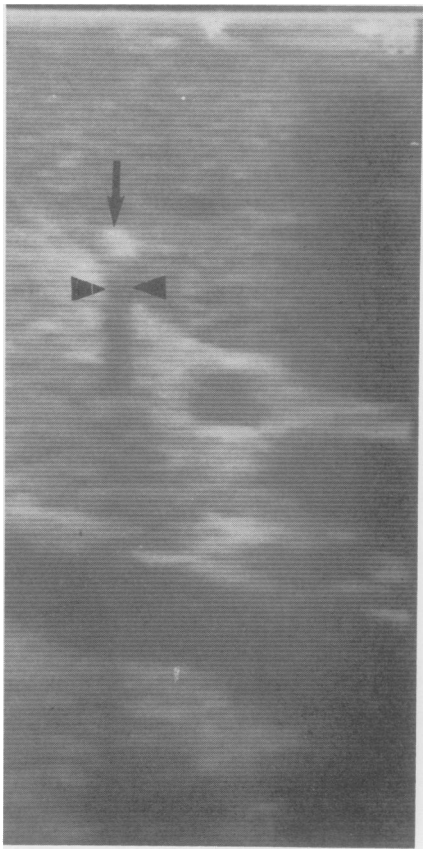


FIG. 8. Calcified granuloma. A nonpalpable echogenic focus (arrow) within the liver is noted with typical acoustic shadowing (arrowheads). This is diagnostic of calcified granuloma.

Discussion

Intraoperative ultrasound is a highly sophisticated tool requiring specialized equipment. Although conventional ultrasound machinery can be used, the more flexible dedicated equipment allows rapid and accurate scanning in the operating suite. Although our study used a dedicated instrument manufactured by one company, many other commercial firms are now producing either specialized machinery or special transducers to be used on existing conventional equipment. This broad development allows easy access for intraoperative ultrasound.

The equipment is relatively expensive; depending on the manufacturer, each transducer costs approximately $7,500, in addition to the basic machinery. However, if disposable sterile covers are used, only a single probe is required. Thus, a single piece of equipment can be used in the operating suite of a general purpose hospital for a variety of intraoperative sonographic procedures.

The technique can be learned quickly and is a valuable tool when an experienced surgeon and an experienced sonologist work together. The diagnostic criteria are similar to conventional ultrasound. However, the orientation, because of the small field of view, may be difficult to un-

TABLE 3. *Comparative Studies*

	No. of Patients	True Positive	True Negative	False Positive	False Negative
Intraoperative ultrasound	49	18	31	0	0
Conventional ultrasound	20	5	12	0	3
Computed tomography	31	6	13	4	8
Angiography	8	4	0	2	2

derstand, particularly for the inexperienced sonologist. Our study, performed on patients undergoing abdominal exploration, has confirmed previous reports of the benefits of intraoperative ultrasound of the liver. These previous studies have shown that clinically known lesions are better defined by intraoperative ultrasound. Secondary abnormalities that are previously unsuspected can be seen, and although it may not be prudent to treat these at the time of surgery, certainly, knowledge of the abnormalities is important.

The technique is safe for patients and for operating room personnel. Since no radiation is emitted, there is less concern in obtaining repeat examinations. When unsuspected, nonpalpable lesions are found with intraoperative sonography, it can also be used to perform the biopsy.

Although liver function studies have been routinely performed in preoperative evaluation of the liver status, recent reports have shown the sensitivity and specificity of percutaneous ultrasound to be uninfluenced by liver chemistry abnormalities.[16] We have not looked at the precise effect of liver chemistry abnormalities and how they might correlate with operative sonography, but probably one would expect they have little effect on the sensitivity/specificity of operative sonography.

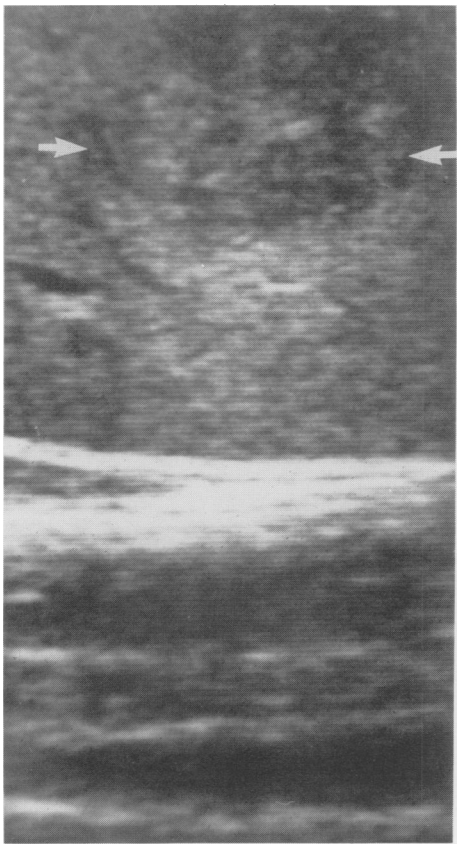


FIG. 9. Metastatic lesion. A metastatic lesion (arrows) is identified. This clinically unsuspected lesion has mixed, but mostly hypoechoic, sonographic characteristics and is irregularly marginated.

TABLE 4. *Accuracy of Imaging Studies*

	Sensitivity*	Specificity†
Intraoperative ultrasound	100	100
Conventional ultrasound	62	100
Computed tomography	42	76
Angiography	66	0

$$* \text{ Sensitivity} = \frac{TP}{TP + FN}$$

$$\dagger \text{ Specificity} = \frac{TN}{TN + FP}$$

TP = true positive.
FN = false negative.
TN = true negative.
FP = false positive.

Operative ultrasound is of great help in the performance of many hepatic procedures. It can give precise localization of tumors and can be used to selectivley tamponade the afferent portal branch to minimize operative bleeding and prevent central retrograde tumor embolic migration in the course of tumor resection.[17]

The sonogram can be very helpful in making decisions as to the appropriate surgical procedure. Since the depth of a tumor can be measured by operative ultrasound, it can help decide between performing a wedge resection or a formal lobectomy. When additional occult lesions are found, they can be biopsied. The results may alter or curtail a planned procedure.

Since the liver is so large, visual or manual assessment constitutes only a part of hepatic evaluation. Routine use of operative sonography is strongly advised to more completely assess liver status.

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Discussion

DR. J. SHELTON HORSLEY, III (Richmond, Virginia): It is a pleasure to have had the opportunity to review this manuscript.

At the Medical College of Virginia in the Division of Surgical Oncology, we have been using ultrasound of the liver as a routine part of our intraoperative evaluation of patients with primary hepatomas and metastatic lesions from the colon and rectum that are confined to an area of the liver that is resectable. It adds about 20–30 minutes to the operative procedure. Our radiologist comes into the operating room. The surgeon performs the ultrasound technique. We have been able to do this with the usual upper abdominal bilateral subcostal incision with an extension up to the xiphoid process. We have felt good about our ability to accurately ultrasound the entire liver.

We have found lesions that were not clinically evident, that led us to decide that the patient was not resectable. In addition, early in our experience we had a patient with a very extensive metastatic colon cancer involving both the medial and lateral segments of the left lobe with some extension into the anterior segment of the right lobe with questionable involvement of the right hepatic vein. With the ultrasound, we could clearly delineate the right hepatic vein to be free from the tumor. We proceeded with a left hepatic trisegmentectomy and, fortunately, the patient is doing well clinically free of disease 18 months later. The delineation of the proximity of the hepatic veins to these tumor masses is another additional benefit of intraoperative ultrasound.

Sitting here in the audience listening to this presentation, Scott Jones turned to me and said, "We should be using ultrasound to scan the liver when we do our primary resections." That is a good suggestion!

I believe it is a helpful technique and I appreciate Dr. Rosato bringing it to the attention of the membership. I would like to ask Dr. Rosato if he has been able to delineate the situation that was alluded to in the previous paper, the so-called benign lesion from the malignant lesion by intraoperative ultrasound?

DR. SHUIN-LIN (Closing discussion): In regard to Dr. Horsley, I appreciate your comments. We always do have radiologists present in the operating room to help us interpret the ultrasound images, which are not as easy for surgeons as the CT scan or other x-ray images to interpret.

Secondly, the anatomic structures are very well outlined by the intraoperative ultrasound, including the hepatic veins. As a matter of fact, last week we had a patient who was suspected to have a lesion involving the hepatic vein. By the intraoperative ultrasound we were able to define the clearance of the hepatic vein, and subsequently, to avoid injury to the hepatic vein and other major vessels and reduce the blood loss.

Third, right now some colorectal surgeons in our institution are using the technique to screen the liver routinely during colon resection to detect if any small lesions are present.

And, finally, to answer Dr. Horsley's question: "Is the intraoperative ultrasound able to define the lesion as malignant or benign?" The answer is no. The intraoperative ultrasound is unable to differentiate the malignant from the benign lesion. If we have a questionable lesion, we will routinely do frozen section biopsy of the lesion to define the pathology.